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Repository Sealing Field Testing Workshop: Proceedings

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September 18 and 19, 1980

D'Appolonia Consulting Engineers, Inc.
10 Duff Road
Pittsburgh, PA 15235

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Office of Nuclear Waste Isolation

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10 Duff Road
Pittsburgh, PA 15235

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II

TABLE OF CONTENTS

PAGE NO.

1.0 INTRODUCTION 1

2.0 WORKSHOP OBJECTIVES. 2

3.0 GENERAL CONCLUSIONS. 4

4.0 FRACTURE CHARACTERIZATION OVERVIEW 6

5.0 PERMEABILITY TESTING OVERVIEW. 11

6.0 REVIEW COMMENTS - I. W. MARINE 15

7.0 PRESENTATIONS. 19

1. OPENING REMARKS
Floyd Burns - ONWI. 19

2. PENETRATION SEALING FIELD TEST PROGRAM OBJECTIVES - FISCAL YEAR 1981
Bob Goodwin - D'Appolonia Consulting Engineers Inc. . . 21

3. PENETRATION CHARACTERIZATION FOR SEAL DESIGN
Peter Kelsall - D'Appolonia Consulting Engineers Inc. . 22

4. NEVADA TEST SITE FIELD PROGRAM
Al Lappin - Sandia National Laboratories. 24

5. PERMIAN BASIN PROPOSED PROGRAM
Larry Picking - Stone & Webster Engineering Corporation 25

6. HYDROGEOLOGIC FIELD INVESTIGATIONS - PARADOX BASIN, UTAH
John Thackston - Woodward-Clyde Consultants 26

7. REENTRY OF ELK RIDGE BOREHOLE, PARADOX BASIN
Tom Frazier - ONWI. 27

8. GULF INTERIOR REGION SALT DOMES FIELD PROGRAM
James Wallace - Law Engineering Testing Company 28

9. BWIP FIELD PROGRAM
Floyd Hodges - Rockwell Hanford Operations
Jack O'Rourke - Woodward-Clyde Consultants. 29

10. LOS MEDANOS FIELD PROGRAM
Chris Christensen and Bob Statler - Sandia National Laboratories. 30

TABLE OF CONTENTS
(cont)

11. ASSE FIELD TEST PROGRAM
Carl Schubert - D'Appolonia Consulting Engineers Inc. . 31

12. BOREHOLE TELEVISION APPLICATIONS AT LOS MEDANOS
Chris Christensen - Sandia National Laboratories. . . . 32

13. THE BOREHOLD SEISVIEWER
Dick Haynie - Birdwell. 33

14. IMPRESSION PACKERS
Clelland MacClain - Lynes 34

15. FRACTURE CHARACTERIZATION USING GEOPHYSICAL LOGS - (1)
Jearald Heflin - Dresser Atlas. 35

16. FRACTURE CHARACTERIZATION USING GEOPHYSICAL LOGS - (2)
Mike Voegele - Terra Tek. 36

17. CALIBRATION MODELS FOR FRACTURED IGNEOUS ROCK ENVIRONMENTS
Mark Matthews - Los Alamos Scientific Laboratory. . . 37

18. FRACTURE CHARACTERIZATION IN GRANITE AT STRIPA
Phil Nelson - Lawrence Berkeley Laboratory. 38

19. WELLBORE DAMAGE SIMULATION PROGRAM
Howard Pratt - Terra Tek. 39

20. FRACTURE CHARACTERIZATION USING FLOW TESTS
Ed Peterson - Systems Science & Software. 40

21. FRACTURE CHARACTERIZATION USING IN-HOLE TRACERS
Wendell Marine - Savannah River Laboratory. 41

22. PERMEABILITY TESTING OF FRACTURES IN THE CLIMAX STOCK GRANITE
Will Murray - Lawrence Livermore Laboratory 42

23. PERMEABILITY TESTING FOR GEOTHERMAL APPLICATIONS IN GRANITE
Bob Potter - Los Alamos Scientific Laboratory 43

24. EQUIPMENT AND TEST METHODS, GRANITE AND BASALT
Keith Kennedy - D'Appolonia Consulting Engineers. . . 44

25. PERMEABILITY TESTING: COMPARISON OF TEST METHODS IN GRANITE
Mike Voegele - Terra Tek. 45

TABLE OF CONTENTS
(cont)

26. TEST METHODS, PARADOX BASIN
John Thackston - Woodward-Clyde Consultants 46

27. TESTING FOR THE EASTERN GAS SHALES PROJECT
Chapman Young - Science Applications Inc. 47

28. TESTING METHODS, GULF COAST SALT AND SHALE
James Wallace - Law Engineering Testing Co. 48

29. TEST METHODS, LOS MEDANOS BEDDED SALT
Ed Peterson - Systems Science & Software 49

30. PACKER COMPLIANCE TESTING
John Gale - University of Waterloo. 50

31. PROBLEMS IN TESTING VERY LOW PERMEABILITY ROCKS IN BOREHOLES
Paul Witherspoon - Lawrence Berkeley Laboratory . . . 51

APPENDIX A List of Attendees 52

REPOSITORY SEALING FIELD TESTING WORKSHOP
THE INN AT LORETTO
SANTA FE, NEW MEXICO
SEPTEMBER 18-19, 1980

1.0 INTRODUCTION

A two-day Workshop to discuss aspects of field testing applicable to penetration sealing was held at Santa Fe, New Mexico, September 18-19, 1980. The Workshop was sponsored by the Office of Nuclear Waste Isolation (ONWI) and organized by D'Appolonia Consulting Engineers, Inc. (D'Appolonia). A total of 40 engineers and scientists attended the Workshop.

The Workshop was conducted in four consecutive sessions as follows:

Session 1 - Review of Existing and Planned Field Test Programs at NWTS sites

Session 2 - Fracture Characterization

Session 3 - Permeability Testing

Session 4 - Overview

Each of the first three sessions consisted of 10 short presentations by invited speakers followed by short discussion periods. Session 4 included technical overviews of Sessions 2 and 3 conducted by invited moderators plus a general discussion period.

Section 2.0 of this report summarizes the objectives of the Workshop as presented to the participants. Section 3.0 is a general summary of the major conclusions of the Workshop as derived by D'Appolonia. Overviews of the Fracture Characterization and Permeability Testing sessions are given in Sections 4.0 and 5.0 respectively; these overviews were initially prepared by D'Appolonia and reviewed by the session moderators (W.F. Brace and P.A. Witherspoon). Section 6.0 contains review comments submitted (independently of D'Appolonia) by Dr. Wendell Marine of the Savannah River Laboratory. Short summaries of each of the presentations prepared from the meeting transcript are given in Section 7.0. A list of workshop participants is given in Appendix A.

Speakers were requested to submit written presentations but this was not mandatory and a common format was not requested. A separate volume including those written submissions received has been distributed to the workshop attendees.

2.0 WORKSHOP OBJECTIVES

Site characterization field programs are ongoing or planned at a number of candidate NWTS sites including the Gulf Interior (salt domes), Paradox Basin (bedded salt), Los Medanos (bedded salt), Permian Basin (bedded salt), Hanford (basalt) and the Nevada Test Site (tuff). In addition, field test programs designed to determine generic rock mass characteristics are underway at a number of sites such as Asse, Stripa, and Avery Island. These field programs are designed to obtain data relevant to site characterization or repository design but as yet there has been little effort to direct field programs to obtain data required for the design of penetration seals. The primary purpose of the Santa Fe Workshop was an exchange of information between participants in the site characterization programs, D'Appolonia personnel responsible for planning repository sealing field test programs and invited experts in various aspects of field testing. Specific objectives were to introduce the managers of the site characterization programs to the requirements for penetration seal design and to evaluate specific test techniques. To the extent possible, it is intended that the same test techniques should be used at each of the potential repository sites.

The performance of a penetration seal will be influenced by the permeability and absorption characteristics of four zones within the seal system:

- the seal material(s)
- the interface between the seal and the host rock
- the disturbed zone in the host rock adjacent to the penetration created by excavation
- the undisturbed host rock

Overall seal performance will be evaluated eventually by emplacing and testing seals under appropriate in situ conditions. No test seals will be emplaced in Fiscal Year 81, however, so that the immediate objectives of the penetration field test program will be to define penetration and host rock characteristics in potential seal zones. This characterization will determine zones requiring sealing and establish baseline conditions for seal design to be used later to evaluate seal performance. Emphasis in FY81 will be given to characterization of boreholes available for study at NWTS sites. Currently there are no shafts or tunnels available for study at NWTS sites, but testing is planned in shafts and tunnels at generic sites.

In a penetration sealing field test program, greater attention must be given to any disturbed zone adjacent to the penetration than would be appropriate for a general site characterization field test program. It is important to define initially whether such a disturbed zone exists and, if so, what is its extent and what are its characteristics in comparison with the characteristics of the undisturbed host rock. Two characteristics of the disturbed zone, fracture characteristics and permeability, are considered to be particularly important and were the subjects for special technical sessions at the Workshop.

A number of potential topics were identified for discussion at the Workshop:

Fracture Characterization

- Definition of which fracture characteristics must be known for seal design
- Definition of the minimum fracture aperture that can significantly influence seal performance and that must be recognized by penetration characterization
- Consideration of the relative advantages and disadvantages of various characterization methods with respect to resolution, zone of influence and applicability to various rock types and penetration environments
- Evaluation of techniques such as overcoring

and sidewall coring for recovering disturbed zone samples

- Review of laboratory testing methods and consideration of the interface between field and laboratory testing

- Future equipment research and development needs.

Permeability Testing

- Review test methods suitable to characterize flow-paths in the disturbed as well as undisturbed zones surrounding a borehole

- Review adequacy of existing equipment for testing in low permeability materials such as those anticipated for seal zones

- Review adequacy of data interpretation methods for analyzing flow paths and pathway characteristics

- For any given test method, define
  - the lower limit of permeability that can be measured
  - the zone of influence in terms of distance from the well bore
  - the ability to distinguish disturbed zone and undisturbed zone effects
  - equipment compliance
  - the influence of imposed test conditions on rock properties including permeability.

Overall, it was intended that the Workshop derive a consensus as to the most suitable test methods for establishing penetration characteristics and permeabilities within the levels of accuracy and precision required for penetration seal design.

3.0 GENERAL CONCLUSIONS

The Workshop included discussion of a wide range of testing and investigation techniques. In accordance with the immediate objectives of the FY81 penetration sealing test program, consideration was given specifically to characterization of boreholes in which direct access is not available; it was acknowledged that later emphasis must be given to

characterization of shafts and tunnels. Particular attention was given also to characterstics of the disturbed zone created by excavation of the penetration.

Inevitably, due to the relatively short duration of the Workshop, it was not possible to devote equal attention to each of the many test methods worthy of discussion, nor to answer fully each of the questions raised by the organizers. Nevertheless, it is believed that the Workshop successfully fulfilled its primary purpose, that of an exchange of information between participants in the various site characterization and penetration sealing programs. Furthermore, a number of valuable conclusions emerged:

1. With the exception of Los Medanos, all of the site characterization programs underway at candidate NWTS sites are currently in a regional characterization phase and few of the programs are yet collecting the detailed and specific information required for seal design. A definite need exists for participants in the seal design program to monitor site characterization activities and to direct these activities to obtain the data required for seal design. Much of the data required can be obtained with relatively little modification to existing site characterization programs.

2. Attention must be given to establishing quantitative performance requirements for seals on a site-specific or medium-specific basis. At present it is not possible to define an acceptable seal zone permeability, hence the required sensitivity of permeability test apparatus is not known.

3. Theoretical and laboratory studies must be conducted to evaluate the probable nature of the disturbed zone, specifically the type of fractures that might be present. It will be especially important to define the probable orientation of fractures relative to the penetration axis. Fracture orientation will largely determine the effects of radial stresses applied to the penetration wall by the seal or by packers. Concentric fractures will tend to close as a radial stress is applied whereas radial fractures will tend to remain open or even enlarge. The overall characteristics of the disturbed zone, including

fracture orientation, aperture and continuity, will determine the suitability of the various methods that can be used for characterization.

4. No fracture detection technique (other than flow testing) was shown to characterize fractures intersecting a borehole in terms of relative conductivity. Further, there is a difference of several orders of magnitude between the resolution attainable with these techniques and the fracture aperture that can produce a significant flow. Fracture characterization techniques should be used to define optimum seal zones by eliminating obviously fractured or disturbed zones but detailed, final characterization prior to seal emplacement, must include sensitive flow testing.

5. Currently, no flow test method exists which will distinguish disturbed zone and undisturbed zone permeability. Suggestions were made, however, that existing equipment (such as the DST or guarded straddle packer) can be modified to achieve the required results. In developing new equipment, and then testing in low permeability materials, attention must be paid to equipment compliance and ensuring that test results are real and defendable.

6. There is a general requirement within the NWTS program for more field and in situ testing. In the context of this Workshop, there is necessity for a dedicated facility for evaluating and calibrating characterization methods. Ideally, this will be a site, or sites, in fractured rock where there is extensive drilling and hydrologic test data available for analysis, and where downhole tests and logs can be run in controlled conditions.

4.0 FRACTURE CHARACTERIZATION OVERVIEW

The following session overview was prepared by D'Appolonia (P.C. Kelsall) and reviewed by the session comoderator, W. F. Brace.

Techniques

The Fracture Characterization Session included discussion of a wide range of techniques that may be used to locate and characterize fractures in boreholes. These techniques included:

- Core logging
- Borehole seisviewer
- Impression packer
- Geophysical logs
  - SP
  - Resistivity (various types)
  - Circumferential resistivity
  - Diplog
  - Caliper
  - Density
  - Neutron
  - Spectral gamma
  - Acoustilog (sonic)
  - Variable density/cement bond
  - Circumferential acoustilog
  - Temperature
  - Radial differential temperature
  - Magnetic induction
  - Noise log
- Microseismic
- Flow meters
- Tracer flow
- Flow testing

In accordance with the objectives of the Workshop, the discussion was directed toward techniques applicable to boreholes rather than techniques applicable in shafts and tunnels. The major observations and conclusions of the Session were as follows:

1) No technique was shown to identify the "relatively conductive" fractures intersecting the borehole. In other words, no technique (excluding direct permeability measurement) exists to positively identify which of two or more fractures intersecting a borehole is the more conductive. Furthermore, most techniques described indicate fracture zones as opposed to single fractures; the capability of most of the methods to delineate a single fracture is questionable.

2) Of the established techniques discussed, the best resolution attainable appears to be of the order of 1/32 inch or approximately 0.5 to 1.0 mm. By comparison, flow testing shows that a single fracture with an aperture of the order of 10^{-4} mm can produce a relatively large flow through a plug zone. Evidently, there is a very large discrepancy between the fracture aperture that can produce a significant flow and the resolution of existing identification techniques other

than hydrologic testing.

3) Several techniques currently under development hold promise for detection of conductive fractures or fracture zones:

   - Flow detection, using spinner-type flow meters or tracer techniques.
   - Sensitive temperature logs
   - Complete waveform acoustic logs, including tube waves.

Resolutions or sensitivities for each of these methods were not precisely defined. Existing spinner logs measure flows in the borehole of the order of a few feet per minute and tracer ejectors may improve this sensitivity by approximately an order of magnitude. Radon profiling conducted at Stripa in an inclined hole improves the sensitivity two or three orders of magnitude further to approximately 10 litres/day in a 3 inch borehole. These numbers were not translated into permeability values. Similarly, the radial differential temperature log has a sensitivity of approximately 1/500 °F, and is therefore a promising technique, but this sensitivity has not been equated with fracture flow or permeability. The Geological Survey of Canada and the US Geological Survey have both shown that fractures generate tube waves more or less proportionally to their hydraulic conductivity. Details on sensivitiy are not yet available.

Attention was drawn also to the possibility of using resistivity logs to delineate the disturbed zone around a borehole. Resistivity tools with different electrode configurations provide varying degrees of penetration away from the borehole wall and are used in the oil industry to identify mud penetration and distinguish invaded zone resistivity from true formation resistivity. It is possible that resistivity logging can be used to distinguish zones of contrasting porosity around a borehole but the sensitivity has not been defined. Also, porosity alone does not yield a permeability; aperture of conductive pore spaces is also required.

A general conclusion from the overall discussion was that it is not

currently possible to define the lower limits of fracture aperture or permeability that can be measured by means other than direct hydrologic tests. A view expressed was that most, if not all, the techniques reviewed appear to be applicable to permeabilities greater than one microdarcy (10^{-9}cm/sec). This raised the question of whether or not it is necessary to detect and characterize fractures by means other than hydrologic testing. The consensus response was that characterization by whatever means available should be attempted, even though the sensitivity might not be as good as we would wish. Logging techniques will enable us to select seal zones relatively quickly and economically and will provide data to assist in interpretation of hydrologic tests conducted in selected zones.

A final point raised concerning techniques was the desirability for a dedicated facility for evaluating and calibrating characterization methods. Ideally, this will be a site, or sites, in fractured rock where there is extensive drilling and hydrologic test data available for analysis, and where downhole tests and logs can be run in controlled conditions. There was general agreement with the suggestion that we need more data, both from repository sites and from generic testing at sites such as Stripa. The more data available, the more confident we will be that our methods of data acquisition and analysis are valid.

Repository Sealing Field Program

While the repository sealing field program is not yet finally defined, it appears that characterization of a specific borehole should be conducted in three stages:

1) Seal zone selection
   The objective of this stage will be overall characterization of the borehole to evaluate the general hole condition (particularly if it is an old well) and identify major fracture zones. Techniques used would be appropriate for rapid characterization of large sections of the borehole and might include core logging (if core is available), conventional geophysical logging, TV inspection and seisviewer inspection.

2) Detailed seal zone characterization
The objective of this stage will be characterization of specific seal zones to the detail and sensitivity possible with available techniques in order to precisely define borehole characteristics such as geometry, sidewall condition and host rock properties. Techniques used in stage (1) will be supplemented with impression packers and additional "exotic" logging methods such as complete waveform acoustic, circumferential resistivity, sensitive temperature and other methods considered appropriate. Laboratory studies will be an important aspect of stage (2) investigations. These will include fabric studies on cores and simulated wellbore damage tests which should provide valuable indications of fracture types that might exist in the borehole damaged zone.

3) Flow Testing
The final stage in characterization will be to conduct highly sensitive flow tests in the potential seal zone or zones. Techniques must be developed to distinguish the disturbed and undisturbed zones around the borehole. Noting the extremely small aperture of fractures that can have a significant effect on flow around a seal, flow testing may be the only means for characterizing the complete set of fractures and microfractures in the seal zone.

A general point forming the basis for this program is that no one technique (including hydrologic testing) is suitable for thorough borehole characterization. Adequate characterization will depend on the use of many complementary techniques, some of which are yet to be developed for routine use.

General Considerations

Several speakers showed schematic drawings of fractures in a damaged zone surrounding a borehole. These were schematic in that very little is known regarding either the probable extent of a damaged zone around a borehole or the probable nature of the fractures within the damaged zone. Laboratory testing, analytical studies and field testing are required to better understand these parameters in order that the required depth of penetration and sensitivity of logging devices can

be defined, at least in approximate terms. It will be particularly important to define the probable orientation of fractures relative to the borehole axis. Orientation of fractures will largely determine the effects of radial stresses applied to the borehole walls by the seal (assuming an expanding material is used) or by packers. Concentric fractures around a borehole will tend to close as a radial stress is applied whereas radial fractures will tend to remain open, or even enlarge.

An important item of discussion concerned the performance requirements for seals. While there was general agreement with the thought that the permeability of the seal zone should approach or equal that of the host rock, this is at present a qualitative criterion since the permeability of the host rock is itself not defined. More attention must be given to defining acceptable permeabilities for host rocks and to defining methods for measuring permeabilities. There was general agreement that the permeability of fractured rocks must be measured underground by a method which will test a large, representative sample of the rock mass. In saturated rocks the macropermeability method used at Stripa may be the most appropriate. New methods must be developed for permeable rocks in the unsaturated zone above the water table. In either case, discussion of acceptable seal zone permeabilities and leakage rates is premature before the overall rock mass permeability at a particular site has been defined. (Nonetheless, a point made by Dr. Marine - see section 6.0 - is that parametric evaluations of plug performance should proceed without knowledge of site specific permeabilities).

5.0 PERMEABILITY TESTING OVERVIEW

The following session overview was prepared by D'Appolonia (K. G. Kennedy) and reviewed by the session comoderator, P. A. Witherspoon.

Purpose

The purpose of the session was to discuss aspects of testing low perme-

ability rocks, specifically methods, equipment, and range and validity of test results reported. Of particular interest to the repository sealing program is the distinction between disturbed zone and undisturbed zone hydraulic properties.

Scope

Eleven invited speakers presented information related to testing in:

- Granite
- Basalt
- Salt
- Limestone
- Shale

Values of hydraulic conductivity for the testing ranged from about 10^{-5} cm/sec to about 10^{-12} cm/sec. The higher values were in basalt and carbonate sequences which are not considered as repository formations but which are found adjacent to repository formations at some sites.

Downhole equipment types varied although five of the eleven programs discussed used identical testing equipment provided by Lynes Inc. (Houston, Texas). Packer materials, lengths, inflation pressures and expansion characteristics were different. Pressure transducers used had wide variations in sensitivity and absolute accuracy.

Testing methods were commonly used techniques, most of which originated in the oil industry, and which have been subsequently refined principally by the development of new and more versatile downhole equipment. Analyses of test results have been conducted using appropriately referenced techniques. In some cases, transmissivity values calculated using different methods had ranges of several orders of magnitude for parts of, or all of, the same test data in a single zone. The validity of analytical methods needs to be reviewed in order to critique these test results.

Discussion of differentiating between the disturbed and undisturbed zones was relatively short. However, the consensus was that neither the borehole equipment nor the methods of testing or analysis could provide data to document which of the two regions is contributing to the test

result. More exotic sampling equipment and tracer techniques will be needed to provide that data differentiation.

Major Discussion Items

From the presentations and two discussion periods that followed, specific information was obtained which should enhance the technical approach to testing associated with the repository sealing program. This information is summarized as follows:

1) Available Borehole Testing Locations
Testing locations in granite boreholes are available at the Nevada Test Site. An asset of this site is that future testing in the subsurface mine will include tracer migration in a single discrete fracture. Testing in salt is of immediate significance to the sealing program. Potential locations include Los Medanos, Paradox Basin and Gulf Coast Salt Domes.

2) Test Equipment and Compliance
A single equipment design for low permeability testing was discouraged by most participants. Instead, performance standards should be established to which each set of test equipment must conform. However, a major problem remains related to evaluating the performance of the testing equipment. There are no adequate test facilities for performing compliance-type evaluations. Until such facilities are developed, downhole equipment cannot be rigorously tested to determine if it meets established performance standards.

The question remains as to what performance standards will be accepted. ONWI should establish these standards in conjunction with current workers in the field. Until such time as the testing equipment is verified as conforming to specifications, the test results will be subject to question and possibly discarded as invalid.

It is pertinent to keep in mind that the critique of test results will eventually be legalistic in addition to technical. Technical verification at the current level of practice associated with nuclear waste studies could fall well short

of satisfying intimate legal entanglements. It becomes critical to provide rigid quality assurance specifications within which testing, data reduction and analysis are conducted. This quality assurance function would provide the framework for the performance specifications.

3) Borehole Data Limitations

Testing in boreholes provides information of only limited value relative to the rock mass as a whole. The value of the data is enhanced when multiple boreholes in one area are tested and a higher degree of confidence can be assigned to the parameter estimates being made. Ultimately, however, subsurface excavations are needed to more exactly investigate the physical and hydraulic properties of the rock. This becomes particularly true with the introduction of fractures as flow pathways in the subsurface regime.

ONWI recognizes these limitations within the context of defining the flow system near or within the repository. However, in the context of the repository sealing program, borehole testing provides adequate background information related to the immediately adjacent host rock. Permeability data from potential seal zones can be obtained from the borehole. The conditions associated with the seal boundary have then been estimated. Subsequently, results from testing the permeability of the seal can be evaluated within the system's entire hydrogeologic environment.

A specific limitation appears to be the inability of most borehole testing to differentiate between the intact rock permeability and the permeability associated with any disturbed zone that may surround the borehole. Typical approaches involving skin effect calculations are not effective due to the pressure response being too rapidly propagated among the fractures within the first 2 to 5 cm of the adjacent rock. Current test methods cannot distinguish between these two zones and different sampling and coring techniques will be needed.

A strong concern voiced by several people related to the radius of influence away from the borehole during testing. It is critical to evaluate the type and degree of porosity associated with the host rock,

in particular, whether a fracture-type or intergranular void-type porosity is present. Fracture-type porosities have radii of influence several orders of magnitude greater than those for the more conventional intergranular-type porosities most hydrogeologists are familiar with.

Testing methods were presented for many different projects. Discussion centered on the differences in results and types of data generated during these tests. In general, the less permeable the rock, the more restrictions on the types of tests that can be used and also on the validity of the results. Detailed evaluation of both test methods and interpreted results are needed for zones with hydraulic conductivity values in the range of 10^{-9} cm/sec or lower.

Finally, the group suggested that increased interchange of testing and equipment data and results is needed. The meeting pointed out the diversity of projects and approaches to testing low permeability rocks. Equipment development is needed immediately and performance standards must be set to evaluate equipment compliance. By a more active integration and communication between ONWI contractors it is expected that the overall program could be accelerated and become more cost effective.

6.0 REVIEW COMMENTS - I. W. MARINE

Dr. I. W. Marine of DuPont (Savannah River Laboratory) acted as an independent reviewer at the Workshop. The following review comments were submitted by Dr. Marine.

1) A parametric study is absolutely essential to determine what difference a borehole plug may make. It is generally conceded that the borehole plug does not have to be less permeable than the native formation. However, the degree to which the plug permeability should approach the permeability of the host rock is not known. This parametric study should not become bogged down on the requirements and criteria for the host rock permeability. It must be truly parametric in the sense that several host rock systems must be assumed and only the difference attributable to a borehole plug or a shaft seal should be investigated.

2) Most of the time of the Workshop was spent on characteriza-

tion of the site, the fractures, and the permeability. These, in my view, only define the conditions that the seal will encounter. These conditions will influence the type of seal and possibly the positioning of the seal in a vertical sense. In practice, however, seal zones may be long and general properties of the rock mass may be applicable as design parameters. These conditions also determine the frame of reference when testing the seal; that is, in order to test the seal, the conditions of the surrounding rock must be known. Whereas many of the techniques discussed at the Workshop are of interest in determining the native state of the rock, these same tests are not all applicable to determining the efficiency of a seal when performing a test.

3) It appears that there are four issues involved in field tests that must be determined.

(A) The damage zone caused by drilling the hole. Some discussion was held on this subject in the Workshop. For example, the work of Terra Tek in the laboratory is aimed at this parameter. There was also some discussion of how to determine the permeability of the damage zone, but most of the permeability tests discussed are generally applied to determining the permeability of the host rock formation assuming that there is no damage zone. For example, a packer test involves the assumption that no fluid leaks around the packer, and this assumes that the fluid also does not leak through a damage zone. Generally, the hydrologic testing community either ignores the damage zone or assumes it does not exist. Thus, almost all of the tests discussed did not address the damage zone. The questions arise "Does the damage zone actually exist? What is its magnitude? Its permeability? Its extent?" There is only a minimal existing program to determine the damage zone. The techniques that could be used to determine its characteristics would be 1) laboratory tests such as those of Terra Tek, 2) observation by overcoring a cored zone, 3) hydrologic methods such as those discussed (i.e., skin effects) but with the requirement of specific focus on the zone near the borehole, and 4) tracer methods (perhaps having the greatest potential).

(B) The second issue is the interface between the plug and the rock. Although there were no programs mentioned to determine this, it is perhaps the most important issue because unlike the damage zone, the common feeling is that it does exist and of all issues may be the most important problem. The Bell Canyon Test which was discussed, was a fine beginning in determining plug characteristics, but its difficulty was that it was unable to

distinguish between leakage through the damage zone, leakage through the interface, or leakage through the plug. The issue of distinguishing these factors should be addressed in future programs.

(C) The third issue is the plug material and the permeability of the plug itself. This is perhaps the least important issue and the one in which the greatest program exists to determine the factors involved. Higher permeability plug material can be compensated for by extending the thickness of plugs, and for most wells where a plug is desired, the plug will extend from the bottom to the top of the well so that great vertical thickess of plug material will be involved. For most plug materials, only a few feet will be sufficient to stop flow through the borehole. This same situation may not be true of the interface zone or of the damage zone.

(D) The fourth issue is the Quality Assurance requirement of plug emplacement. After spending much time on design, the field operation commonly does not go according to the design. For a radioactive waste repository it is absolutely essential that the best techniques be used and that the quality of the plug be assured. This involves more than simply keeping records of how the plug was emplaced, but also verifying that the conditions of placement are actually as designed. Plugs and seals are doubly critical because repair in redoing is more difficult than the first attempt.

On all of these issues the program should consist of (1) laboratory tests, (2) field tests, (3) in situ tests, and (4) monitoring plug performance. The laboratory tests are the least important but these are the ones to which the largest program is now devoted. Field tests such as the Bell Canyon Test are essential in order to understand the problems of plug emplacement. More such tests are needed. However, one should be very careful that the public does not believe that every test must be absolutely successful. The program should be designed to truly explore the subject of well plugging rather than to simply demonstrate that successful plugs can be emplaced. Monitoring actual plugs in a repository is a particularly thorny issue because, in large part, the procedure will be developed and quality assured, and then from that point on it will largely be a matter of faith that the plug is working. To attempt to put monitoring devices in a plug may itself destroy plug integrity.

7.0 PRESENTATIONS

The following brief summaries of the 30 oral presentations made at the Workshop were prepared by D'Appolonia from the tape transcripts. The bold number at the top of the page is the presentation number.

OPENING REMARKS

Floyd Burns ONWI

ONWI's overall goal is to develop plans for repositories in a variety of rock types. Geological exploration programs are underway in dome salt, bedded salt and granite and ONWI's responsibilities will soon be extended to other media including basalt, tuff and shale. Within the overall program an ONWI subtask is to develop seals and backfill for all penetrations in all the rock types considered for repositories.

The repository sealing program will follow the logical progression of design, construction and testing. The objectives of the current design stage are to develop plans and specifications for seal configuration, materials, construction techniques and performance requirements. D'Appolonia has the responsibility for developing designs for each medium and for achieving the performance specifications. They will be supported by activities in two main areas - field testing, the subject of this workship, and laboratory testing which will be the subject of a future workshop.

ONWI has the current capability to authorize field testing at the Los Medanos site (bedded salt), at Hanford (basalt), in the Paradox Basin (bedded salt) and in the Gulf Coast region (dome salt). In each of these cases, field testing may be authorized as an addition to existing field programs. Other rock types, and other contractors may be added as appropriate.

Three main objectives may be listed for this field testing workshop:

1) Identify areas in which field testing should make a significant contribution to design input

2) Identify feasible tests

3) Assign priorities for tests and develop an ordered sequence for a field testing program

While these issues may not be resolved at this workshop, ONWI encourages each participant to communicate freely ideas or suggestions for future programs either with OWNI or D'Appolonia.

PENETRATION SEALING FIELD TEST PROGRAM OBJECTIVES - FISCAL YEAR 1981

Bob Goodwin - D'Appolonia Consulting Engineers Inc.

A number of matrices are presented to illustrate the role of field testing within the overall seal design program. For the FY81 Program, priority has been assigned to field tests required to investigate the following penetration characteristics:

- Fracture characteristics
- Fracture distribution
- Extent of the disturbed zone
- Permeability of disturbed and undisturbed zones
- Sidewall characteristics
- Groundwater geochemistry

These priorities are determined by the immediate necessity for design parameters, by the necessity for evaluating test techniques in certain areas and by the feasibility of testing in FY81. Fracture characterization and permeability testing are areas of particular concern and are accordingly the subjects of specific sessions at this workshop.

Emphasis will be given to field tests at candidate repository sites but generic tests will be conducted also as appropriate. Design parameters are required for all types of penetration - boreholes, shafts and tunnels but at present no shafts are available for testing at repository sites. Emphasis is thus placed on testing in boreholes.

3

PENETRATION CHARACTERIZATON FOR SEAL DESIGN

Peter Kelsall D'Appolonia Consulting Engineers Inc.

D'Appolonia is responsible for directing a field test program designed specifically to obtain input for penetration seal design. In this program priority will be given to fracture characterization and permeability testing in boreholes drilled from surface. Priority is given to boreholes which are currently available for testing; subsequently in the program, increasing emphasis will be given to shafts and tunnels.

The current design goal for repository seals is that the actual leakage rate should be less than the maximum allowable leakage rate by a specified factor of safety. A useful qualitative goal for this workshop to consider is that the permeability of the seal should at least approach that of the host rock. Seal design must take into account the characteristics and permeability of four zones, the seal material, the interface between the seal material and the host rock, the disturbed zone in the host rock adjacent to the penetration sidewalls, and the undisturbed host rock.

While there is a considerable overlap between penetration sealing field programs and general site characterization field programs, a number of special considerations apply to the former. Most importantly, penetration sealing field programs are concerned more specifically with characteristics of the penetration and with characteristics of the host rock immediately adjacent to the penetration. Local anomalies such as a single fracture adjacent to the penetration may have an important influence on seal performance whereas repository performance will be influenced more by fracture systems and bulk properties of the rock mass. Also, in boreholes requiring sealing, penetration characteristics determined by remote investigation will not be confirmed by later inspection.

Certain techniques for penetration and fracture characterization in boreholes are readily identified. An objective of the Fracture Characterization Session will be to evaluate these techniques, as well as to identify other methods which may be appropriate. Other objectives will be to identify relevant fracture characteristics and assess research and development requirements. Attention should be given to techniques applicable to fracture characterization at or close to the penetration sidewall.

4

NEVADA TEST SITE FIELD PROGRAM

Al Lappin Sandia National Laboratories

The Nevada Nuclear Waste Storage Investigations include participation by Sandia, LASL, L^3 and the USGS. Site characterization activities are restricted to an area of tuffs at Yucca Mountain in the southwest part of the NTS. Field testing is underway or planned in tuffs in the G-Tunnel and in the Climax Stock granite both located in the northern part of the site; these sites are not being considered for waste storage. No facilities exist at the Yucca Mountain site to support field testing.

Field tests underway or planned include:

- Spent fuel test in granite at the Climax Stock
- Nuclide migration test in granite at the Climax Stock
- Water migration heater test in non welded tuff in G- Tunnel
- Nuclide migration test in non welded tuff in G-Tunnel
- Thermomechanical heater test in non welded tuff in G-Tunnel

An important point to note is that the tests in tuff will be conducted above the water table in non welded tuff. These rocks have approximately 25 percent porosity and are 98 percent saturated but they do not flow water other than localized seeps. The candidate repository site at Yucca Mountain is in welded tuffs below the water table. Two deep (6000 feet) boreholes have been drilled at Yucca Mountain and two more are planned for FY81. Hydrologic testing will be conducted in one of the planned holes; otherwise, detailed test plans for the holes have not been developed.

Little consideration has been given to sealing at NTS but it is noted that the tuffs are extremely variable both in mineralogy and structure and that seal design may be affected greatly by the location of the seal in the penetration. Other speakers at the workshop noted the difficulty related to permeability testing in nonsaturated materials such as the tuffs in G-Tunnel.

PERMIAN BASIN PROPOSED PROGRAM

Larry Picking - Stone & Webster Engineering Corporation

Regional geological characterization studies will be initiated by Stone & Webster in bedded salt of the Palo Duro and Dalhart Basins in FY81. Concurrently, two deep exploration wells will be drilled in the Palo Duro Basin by the Texas Bureau of Economic Geology (TBEG). Current plans are that these wells will be cased after drilling, logging and drill stem testing. Previous drill stem tests by TBEG have been disappointing, reportedly because of inadequate packer seals.

6

HYDROLOGIC FIELD INVESTIGATIONS - PARADOX BASIN, UTAH

John Thackston - Woodward-Clyde Consultants

Regional geological characterization studies by the USGS in the bedded salt of the Paradox Basin of southeastern Utah identified four areas for consideration as potential repository sites:

- Lisbon Valley
- Salt Valley
- Gibson Dome
- Elk Ridge

Geological studies now being conducted by Woodward-Clyde are concentrated in two of these areas, Gibson Dome and Elk Ridge.

Three exploration boreholes drilled in Salt Valley by the USGS in 1978 have been plugged with cement. Woodward-Clyde has drilled one deep (6200 feet) borehole at Gibson Dome and two more holes are planned in 1981 and 1982. Three deep (4300 feet) holes will be drilled in 1981 and 1982 at Elk Ridge. Geophysical logging, geotechnical testing to monitor deformation behavior, and hydrologic testing to measure formation permeabilities and collect groundwater samples will be conducted in these holes. Hydrologic testing will employ a selective completion tool designed to isolate and test up to nine separate permeable zones in each well. Further details of the hydrologic testing methods are given in a separate presentation by the same author.

REENTRY OF ELK RIDGE BOREHOLE, PARADOX BASIN

Tom Frazier ONWI

Woodward-Clyde is developing plans to reenter an abandoned oil well, Kubat Government #1, which was drilled and plugged in the Elk Ridge area of the Paradox Basin in 1958. This hole is located in a critical part of Elk Ridge and is to be reentered primarily for logging purposes. In addition to logging, it may be appropriate to attempt to recover the cement plugs either by coring or, preferably, overcoring. Records show that three plugs were set, from 130 to 180 feet depth, from 1300 to 1400 feet, and from 3300 feet to the bottom of the hole at 3500 feet. The two lower plugs were set in limestone, apparently to protect the salt zone from overlying and underlying aquifers. Woodward-Clyde intends to reenter the well in February, 1981. Specific plans for recovering or testing the plugs will be developed by cooperation between Woodward-Clyde, D'Appolonia and ONWI.

8

GULF INTERIOR REGION SALT DOMES FIELD PROGRAM

James Wallace Law Engineering Testing Company

Regional site screening selected eight salt domes, three in Texas, two in Louisiana and three in Mississippi as candidate repository sites. One of these domes has since been eliminated and regional geological characterization studies are currently underway at the other seven.

Regional studies have been concerned mostly with the overall structure of each dome, including the sediments surrounding the salt, rather than with the salt itself although at least one boring has been completed into salt at most of the sites. Hydrologic tests have been conducted in the sediments, in the caprock, and at the caprock interface, but not in the salt. Each hole drilled into the salt by Law has been plugged in the salt.

Also part of the NWTS Program, deep core holes have been drilled into the salt at two of the candidate domes, Vacherie and Rayburn's in Louisiana, by Louisiana State University. These holes are open in the salt and are available for further testing.

BWIP FIELD PROGRAM

Floyd Hodges Rockwell Hanford Operations
Jack O'Rourke Woodward Clyde Consultants

Borehole plugging field tests are planned as part of the overall site characterization and repository design efforts underway for the Basalt Waste Isolation Program at Hanford, Washington. Tests will be conducted in three stages:

1) Shallow borehole tests

2) Tests in boreholes or shafts intersecting tunnels in the Near Surface Test Facility

3) Tests at repository depths

Tests planned for shallow boreholes, at depths in the range 50 to 150 feet, above the water table, are the subject of this presentation.

Several questions were raised regarding the test technique as described in the presentation. From the test results alone it may not be apparent whether any leakage observed is passing through the plug per se or along the instrument tubes which penetrate the plug. Dyes will be injected during the flow tests, however, and the plugs will be overcored to investigate preferred seepage paths. The permeability of the host basalt rock has not been tested, hense test results will be representative of the complete plug system, possibly including the host rock and the interface as well as the plug along. Tests in shallow boreholes may not be representative of conditions at repository depths but such tests involve fewer unknowns and technical problems, and are a logical starting point for a progressively more realistic test program.

10

LOS MEDANOS FIELD PROGRAM

Bob Statler and Chris Christensen - Sandia National Laboratories

A cement plug has been installed and tested in an abandoned 8-inch diameter geological exploration hole at Los Medanos, the site of the proposed Waste Isolation Pilot Plant. The plug was installed in anhydrite at a depth of 4495 feet and was exposed to a pressure of 1800 psi in an underlying aquifer. The plug was tested by monitoring flow into a test chamber above the plug; no instrumentation penetrated the plug itself. The observed flow indicated a nominal permeability (assuming an area of flow equivalent to the cross-sectional area of the plug) of 50 microdarcies (5×10^{-8}cm/sec). Taking into account laboratory-measured values of 1 microdarcy (10^{-9}cm/sec) for the anhydrite and 0.5 microdarcies (5×10^{-10}cm/sec) for the grout, the interface permeability may be as high as 500 microdarcies (5×10^{-7}cm/sec).

Sandia is planning to recover by overcoring a cement plug set in a 4-inch diameter potash exploration hole in 1975. Acknowledging that this plug does not have a long history, an advantage is that the plug composition and placement technique are well known. Recovery of the plug and geochemical analysis may indicate whether there is a serious problem with the use of cement as a plugging material. Sandia has previously recovered a 17-year old plug which did not show any evidence of deterioration. (Sandia acknowledges possible technical difficulties with overcoring the plug at depth).

Tentative plans exist also to place an open-center cement grout plug in the overcored hole from which the potash plug is recovered. The open center of the plug will enable testing and logging and, as appropriate, different mixes can be set in different sections of the hole. Sandia is also suggesting installing a bank of cement plugs, using different mixes, which can be recovered and tested after a long period, perhaps 30 years.

ASSE FIELD TEST PROGRAM

Carl Schubert D'Appolonia Consulting Engineers Inc.

Under a bilateral agreement between the United States and the Federal Republic of Germany, test facilities will be made available at the Asse Salt Mine in West Germany. Two main types of test are currently being considered: Brine Migration and Waste/Rock Interaction.

A significant aspect of the Asse testing with respect to penetration sealing is that the tests will be conducted in boreholes drilled from the mine floor, partly within the disturbed zone produced by mining and stress relief. Testing at Asse will provide valuable generic information of salt regarding the extent of the disturbed zone around the mine openings and appropriate techniques for fracture characterization.

12

BOREHOLE TELEVISION APPLICATIONS AT LOS MEDANOS

Chris Christensen Sandia National Laboratories

A downhole televison camera was used to select suitable parker sealing locations as part of the Bell Canyon Test. The method proved successful in identifying wellbore irregularities such as washouts and double-barrel shapes which were not revealed by caliper logs.

Different lamp configurations are used with the camera for dry or fluid-filled holes. A built-in compass may be added for orientation control. The instrument used at Los Medanos had a 4-inch diameter and a depth limitation of 3000 feet. Sandia is currently examining a color television camera with a 2-inch diameter and a 5000-feet depth limitation.

As pointed out by several participants, other cameras are commercially available or are being developed. A major limitation with all downhole optical cameras is that they require either a clear drilling fluid or a dry hole for adequate resolution.

THE BOREHOLE SEISVIEWER

Dick Haynie Birdwell

The borehole seisveiwer (or televiewer) provides a continuous acoustic picture of a borehole wall generated from the reflections of an acoustic signal transmitted by the logging unit. The continuous log of the borehole wall is generated as the instrument is pulled up the hole and simultaneously rotated. Features such as fractures and voids reduce the amplitude of the reflected signal and are detected as a change in signal intensity in the surface recording equipment. Orientation to magnetic north is indicated by the pulse of a magnetometer installed in the tool.

The minimum detectable crack width is believed to be approximately 1/32nd of an inch or 0.5 mm. The tool does not require clear drilling fluid but the signal is disrupted in muds containing long polymers or oil emulsions, in coal formations and in gassy holes. The maximum hole size is approximately 13 inches. Another application of the tool is as a caliper using the transit time of the signal rather than the amplitude.

The author noted that sufficient funding has not been available to develop the seisviewer to its full capabilities. This situation is unlikely to change since the potential market for the tool is very small compared with the total turnover of the logging industry. Some oil companies, including Amoco, Shell and Mobil have conducted internal research with the seisviewer and the USGS in Denver has two operational tools.

14

IMPRESSION PACKERS

Clelland MacClain Lynes Inc.

The impression packer consists of an inflatable packer and a sleeve of soft rubber with little or no elasticity. When the rubber sleeve is pressed against the borehole wall it retains a permanent impression of sidewall features such as fractures or vugs. The method was developed principally for distinguishing between natural and artifically induced fractures in drill core. Normally the packer is run in a 10-foot length on the tubing string but a wireline version can also be developed. Orientation is obtained from a compass or an orientation tool mounted on the packer.

The resolution of the technique is not known but extremely fine textural features have been recorded. The impression provides no information on borehole geometry or size unless the hole is too large for the packer used. Standard tools are available for borehole diameters from 2 inches to 20 inches. Normally, the packer assembly is custom-developed or modified for a particular application. A disadvantage of the technique, compared to continuous logging devices such as the seisviewer, is that impressions must be taken in short, discrete lengths. Twenty feet is probably the practical length limit but 10 feet is preferable. Centralizers are used to protect the impression during withdrawal but problems may arise in highly deviated holes. The speaker emphasised the importance of running the impression packer in combination with other methods since no one logging device can provide all the information needed.

FRACTURE CHARACTERIZATION USING GEOPHYSICAL LOGS - 1

Jearald Heflin Dresser Atlas

Commercially available well logs were not developed specifically for the purpose of detecting fractures. Consequently, the resolution of the logging devices is generally not suited to detection of single fractures. The speaker stressed the importance of understanding the vertical resolution of each log used, as well as the depth of penetration, the volume of the rock surveyed and the fundamental method employed. In comparing two log responses it is important to consider whether the measurement technique is the same in each case and whether the same rock property is being measured.

Generally, commercially available logs are suited to detecting "fracturing" or fracture systems rather than isolated individual fractures. An exception might be fractures containing uranium mineralization, which would be detected by a spectralog, or a fracture with sufficient relief to be detected by the high resolution dip log.

16

FRACTURE CHARACTERIZATION USING GEOPHYSICAL LOGS - 2

Mike Voegele Terra Tek

Terra Tek has evaluated various techniques commercially available for detecting induced fractures. The fracture detection device is to be run as part of a wireline hydraulic fracturing tool and must withstand pressures up to 10,000 psi and temperatures up to 200F.

Promising methods include passive seismic devices (which are generally used to detect fracture propagation), the circumferential acoustic log (for vertical fractures), horizontal spinner type flowmeters (which require natural or induced fluid flow), the circumferential resistivity log, impression packers, spectral gamma logs, and the radial differential temperature log. The Department of Transportation is developing a modular tool, including acoustic, radar and resistivity devices, for fracture detection in horizontal boreholes drilled ahead of tunnels.

Most of the techniques reviewed require a fluid filled hole or fluid movement in the hole for an adequate response. Techniques which might respond in a dry hole include the dipmeter (using pressure pads and/or conductive fluid delivered to the electrode pads), induction logs, borehole television, impression packers, calipers and spectral logs.

CALIBRATION MODELS FOR FRACTURED IGNEOUS ROCK ENVIRONMENTS

Mark Matthews Los Alamos Scientific Laboratory

Most logging tools have been developed for oil exploration and are calibrated for use in marine sediments. Models are being developed for calibrating logging tools in fractured igneous and metamorphic rock types. Three models have been constructed at the Denver Federal Center. Each consists of an 8 feet x 10 feet x 8 feet block, two granite and one basalt, containing saw cut fractures. Core holes will be drilled in the center of each block and log responses will be compared against measured physical properties. Fracture apertures range from 1/8-inch to 1/16-inch with some fractures intersecting the hole and some not intersecting. These models are available for public use free of charge. A fourth model, built at IRT in San Diego, consists of 32, 2-inch thick, 4 feet by 4 feet granite slabs stacked inside a tank which can be fluid filled and heated. This model will be used to calibrate log response to a fracture system.

18

FRACTURE CHARACTERIZATION IN GRANITE AT STRIPA

Phil Nelson Lawrence Berkeley Laboratory

Various fracture detection methods have been employed at Stripa as part of the joint Swedish and U.S. field test program. Good correlations were obtained between caliper, differential resistance (dipmeter), sonic and resistivity logs, and between these logs and fractures observed in cores. At least in granite, in which the borehole wall is very smooth, fractures can be detected with a caliper. P-wave transit time sonic logs were also successful but it is suggested that better results may be obtained analyzing the complete sonic wave train. Reference is made to work by the USGS where good correlations were obtained among shear and tube wave amplitudes, P-wave transit time and fractures observed in cores and televiewer logs. A general observation is that several logs should always be run in combination. Cross plots may be used to estimate porosity, but interpretive methods for low-porosity igneous rocks lag behind standard methods used for sediments.

Cross-hole seismic measurements appear useful for indicating fractured zones although results may be influenced by mineralization in fractures as well as by fracture density. Another promising technique for detecting permeable zones uses tracer or flow profiling. At Stripa various flow profiling techniques have been used to monitor flow rates in boreholes ranging from hundreds of litres per day (with tracers) to hundreds of litres per minute (with spinners).

WELLBORE DAMAGE SIMULATION PROGRAM

Howard Pratt Terra Tek

Terra Tek is conducting a series of experiments designed to simulate the damage zone produced around a borehole by the drilling process. Boreholes are drilled using 7-inch bits with the rock sample enclosed in a triaxial cell and subjected to full scale simulated in situ stresses and drilling parameters. Three rock types are to be used, anhydrite, salt and granite, and two drill bits, a 7-inch roller cone and a 7-inch diamond bit. The purpose is to obtain at least a qualitative illustration of the type of damage that may result from drilling a borehole. A cement plug will be set in one of the anhydrite samples and permeability tests will be conducted on the plug and the host rock material.

Some concern was raised by participants regarding the exact simulation of in situ stress conditions. Removing the sample from the quarry and transporting it to the laboratory may cause irreversible stress relief damage. In addition, the boundary conditions around the thin wall cylinder in the triaxial cell do not correspond to those in situ. The speaker agreed that it will be advisable to run some tests with smaler bits in order to check for possible borehole size effects. Generally, the participants did not consider that concerns regarding stress state simulation would detract from the value of the experiments.

20

FRACTURE CHARACTERIZATION USING FLOW TESTS

Ed Peterson Systems Science & Software

Fracture widths responsible for flow can be estimated from arrival times and flow rates recorded from flow tests. In the Bell Canyon Test, a flow around the plug of 0.6 litres/day, under a driving pressure of 1800 psi, is equivalent to a system permeability of the order of 50 micro-darcies (approximately 5×10^{-8}cm/sec). Tracer arrival times indicate that the width of the largest single fracture responsible for this flow cannot be greater than 10^{-5} cm. Evidently, very small fractures, which cannot be detected by visual examination or logging, can be responsible for significant flow rates.

FRACTURE CHARACTERIZATION USING IN-HOLE TRACERS

Wendell Marine Savannah River Laboratory

An extensive series of hydrologic tests was conducted at the Savannah River Plant in the period 1961 to 1972 as part of a study of the feasibility of storing high-level defense wastes in metamorphic bedrock below the Coastal Plain. Techniques used to locate fracture zones included core logging and geophysical logging which were able to locate fracture zones but not individual fractures. Individual fractures were successfully located using packer tests and trace ejector techniques.

22

PERMEABILITY TESTING OF FRACTURES IN THE CLIMAX STOCK GRANITE

Will Murray Lawrence Livermore Laboratory

Permeability tests are planned in conjunction with the spent fuel and nuclide migration tests in the Climax Stock granite at the Nevada Test Site. The tests will be conducted on discrete fractures isolated by packers in boreholes drilled from tunnels at a depth of 1400 feet in the test facility. The location is above the water table and the tests will be performed with air. Concern was raised regarding the difficulty of interpreting two-phase flow if the fractures contain some water.

The speaker also noted the possibility of using air permeability tests to investigate the damage zone around the tunnels. The underground facility may also provide the opportunity for emplacing test seals in granite.

PERMEABILITY TESTING FOR GEOTHERMAL APPLICATIONS IN GRANITE

Bob Potter Los Alamos Scientific Laboratory

Drill stem permeability tests were conducted in granite at depths of greater than 6000 feet at the Fenton Hill geothermal site. Measured values were in the range 0.1 to 10 millidarcies (approximately 10^{-7} to 10^{-5}cm/sec). Fracture zones were detected using a combination of geophysical logs including caliper, resistivity, gamma, neutron, density, spectral gamma and full wave sonic. The speaker recommended temperature logging during drilling as a rapid, inexpensive means for detecting fracture zones.

24

EQUIPMENT AND TEST METHODS, GRANITE AND BASALT

Keith Kennedy D'Appolonia Consulting Engineers

Test methods, equipment and results are described from borehole tests in granite at the Atomic Energy of Canada site at Atikokan, Ontario and in basalt at the Hanford Reservation in Richland, Washington. Four basic test methods were employed depending on the range of permeability expected from the zone tested: slug withdrawal, pulse (slug injection), drill stem tests and air-lift/recovery. In some cases different test methods indicate different results for the same zone. The testing in 15 fractured granite zones was done at depths up to 4500 feet with calculated permeabilities in the range of 10^{-7} to 10^{-11}cm/sec. At Hanford, testing was done mostly in the more vuggy and occasionally fractured interflow zones. Permeabilities ranged from about 10^{-4} to 10^{-8}cm/sec. By contrast permeabilities in the collonade/entablature fractured zones ranged from about 10^{-7} to 10^{-10}cm/sec.

PERMEABILITY TESTING: COMPARISON OF TEST METHODS IN GRANITE

Mike Voegele Terra Tek

In situ borehole permeability tests were conducted as part of a feasibility study for a compressed air energy storage scheme in foliated granite in Maryland. Single packer and straddle packer methods were used and results were analyzed using three methods: steady state (constant flow and constant pressure); curve matching and iterative approximation for transient conditions; Horner shut-in analysis (drill-stem test).

Results obtained were in the range 10^{-11} to 10^{-15} cm^2 (approximately 10^{-6} to 10^{-10}cm/sec). Although the speaker reported that the cores contained relatively few fractures, other participants noted that matrix permeability values for granite may be as low as 10^{-18} cm^2 (approximately 10^{-13}cm/sec). Good agreement was found between results obtained by steady state analysis and by transient analysis, but in two cases the results obtained by shut-in analysis were approximately two orders of magnitude lower than those obtained by other methods. The speaker referred to type curves from shut-in tests noting that wellbore skin or damage effects may be revealed by the pressure behavior in the early part of a drill stem test.

26

TEST METHODS, PARADOX BASIN

John Thackston Woodward-Clyde Consultants

Hydrologic tests are being conducted in the Gibson Dome #1 borehole in the Paradox Basin. Hydrologic units are distinguished by "short-term" drill stem tests and "long-term" tests (approximately 1 week duration per test zone) will be conducted in selected zones. These zones will be isolated using a commercially available selective completion tool cemented in the well. Tests will be conducted in permeable formations and in relatively tight zones, including some tests in the salt section. It is anticipated that the long-term tests using straddle packers to isolate the screened zones will measure permeabilities in the microdarcy (approximately 10^{-9}cm/sec) range.

The speaker noted that there is a considerable existing oil field technology that can be adapted for geotechnical use with minor modification. Problems with drill stem tests include equipment malfunctions such as sticking shut-in valves, premature packer release and electrical shorting in the wireline. Also, there can be problems with interpretation if the results do not match the type curves used for analysis. With one test result in the salt section the speaker suggested that departure from the type curve was due to salt creep; other explanations could be suggested, however, and there is no way to determine the true situation.

TESTING FOR THE EASTERN GAS SHALES PROJECT

Chapman Young Science Applications Inc.

Hydrologic tests will be conducted in Ohio as part of a feasibility study for recovering unconventional gas from the Eastern gas shales. The gas in these shales is stored in the matrix but production is controlled by natural or induced fractures. In a porous/fractured system, point to point measurements between wells are required for adequate interpretation. Two wells will be drilled offset from an existing well so as to examine system anisotropy. A major problem with wellbore testing of this type is that the wells will not intersect a statistically valid sample of the fractures. Explosive simulation will be used in the bottom of the wells to improve the connection between the wells and the natural fracture system.

28

TESTING METHODS, GULF COAST SALT AND SHALE

James Wallace Law Engineering Testing Co.

Permeability testing has been conducted in the sediments surrounding the salt domes, in the caprock and at the salt-caprock interface. All tests were steady state pump tests in open holes, using packers to isolate zones such as the salt-caprock interface. Permeability values obtained are in the range 10^{-5} to 10^{-6} cm/sec or greater.

TEST METHODS, LOS MEDANOS BEDDED SALT

Ed Peterson Systems Science & Software

Borehole permeability tests were conducted in two zones in salt using a "guarded" system with four packers. In low permeability formations, this guarded packer system is one method of determining if flow is occurring around the central packers isolating the test interval. Measured permeabilities were in the range 5 to 20 microdarcies (approximately 5×10^{-9} to 2×10^{-8} cm/sec).

The speaker noted that cross hole testing is required to obtain correct fluid velocities and to enable proper interpretation of test results. With a single borehole test different interpretations are obtained according to whether the system is analyzed as a porous or fractured medium. Knowledge of true fluid velocities is required particularly for radionuclide migration studies.

With the guarded system, flow in a disturbed zone can be detected as flow into the guarded interval although in cases of very low flow it may not be possible to distinguish flow in a damage zone and flow around the packer. Assuming a uniform system, test results can be analyzed to show the depth of influence of the test; accordingly, it should be possible to design tests to investigate variations in permeability away from the wellbore by varying the test duration.

30

PACKER COMPLIANCE TESTING

John Gale University of Waterloo

Laboratory tests have been conducted to compare the compliance of air and water packers. The packers were set in a steel tube and the pressure responses obtained during flow tests were compared with the response of a steel plug used in place of the packers. Different results obtained with the three systems have not been explained. While there may be a compliance problem the results could be explained also by minor, unobserved leaks.

Laboratory tests have been conducted also to investigate cement grouting of natural fractures in granite samples by comparing permeabilities before and after grouting. One observation has been that the stress-permeability responses of natural and induced fractures may be significantly different.

Extensive field testing has been conducted at Stripa, one aspect of which has been to compare permeabilities determined by steady state and transient methods. In general, there does not appear to be a one to one correspondence between the permeabilities measured by the two methods. A general observation is that the volume of water in the test interval in the borehole should be minimized with respect to the volume of water in the rock porosity influenced by the test. In low porosity rocks, observed pressure responses are related to displacements of very small volumes of fluid.

PROBLEMS IN TESTING VERY LOW PERMEABILITY ROCKS IN BOREHOLES

Paul Witherspoon Lawrence Berkeley Laboratory

Rocks with very low permeabilities are difficult to test in boreholes because the pressure transients cannot penetrate to significant distances over practical periods of time. In situ test methods, such as the Stripa Ventilation Test, are required to obtain reliable rock mass permeability values. At Stripa, measured rock mass permeabilities were in the range 10^{-8} to 10^{-9} cm/sec; permeabilities at least one order of magnitude lower may be obtained with straightforward modifications to the technique.

Repository Sealing Field Testing Workshop
September 18-19, 1980
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